Precision Application of Aldicarb to Enhance Efficiency of Thrips (Thysanoptera: Thripidae) Management in Cotton

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ABSTRACT Field studies were conducted during 1999–2001 in two climatic/edaphic areas of Georgia (Southern Piedmont and East Gulf Coastal Plain) to test the hypothesis that precision placement of aldicarb with cotton seed in hill planting at spatially specific intervals could decrease insecticide use for management of tobacco thrips, *Frankliniella fusca* (Hinds). Precision-placed aldicarb controlled thrips during cotton seedling stages using per ha amounts of one-half or less than standard in-furrow application rates with no significant differences in yield. Residual analysis of cotton plants showed that plants in precision placement plots had as much or more aldicarb and aldicarb metabolites present as compared with cotton treated with conventional in-furrow treatments. Higher rates of precision-placed aldicarb did cause phytotoxic burning early in the growing season, but no significant impact on yield was observed.

KEY WORDS Cotton, aldicarb, Temik, *Frankliniella fusca*, precision placement, tobacco thrips

TOBACCO THRIPS, *Frankliniella fusca* (Hinds), are early season pests of cotton in the southeastern United States. Feeding injury causes yellowing, stunting, and overall plant decline (Davidson et al. 1979). In 2001, 93% of the cotton grown in the United States was infested with thrips, resulting in an estimated loss of 235,996 bales (Williams 2002). Each year, almost three million ha of cotton is treated to control thrips at a cost of $81 million (Williams 2001). Current management approaches for thrips in cotton include the use of aldicarb (Temik 15G, Bayer Crop Science, Kansas City, MO) applied at planting. Each year, over one million kg of aldicarb is applied to cotton in the United States at a cost of over $5 per acre (Thelin 1998, Williams 2001). Aldicarb, a systemic carbamate insecticide, effectively controls thrips in cotton, but is expensive and hazardous to use and poses a substantial risk for both human health and the environment (Hayes 1982). Aldicarb and its metabolites and degredates may leach to groundwater from the soil in quantities high enough to potentially affect human health. Aldicarb has been found in wells in 12 states in the United States in concentrations above the health advisory limit of 10 parts per billion (Howard 1991).

In cotton and several other cropping systems, current planting technology allows for seeds to be placed in specified intervals along the row. However, pesticides used at planting are usually applied in a continuous stream either in-furrow or banded over the row, so much of the pesticide is deposited away from the target. An alternative method of application would be to precisely place the pesticide with the seed at planting, which could reduce the total per ha application by one-half or more.

The objectives of this study were to evaluate the efficacy of precision-placed aldicarb treatments in comparison with traditional in-furrow treatments for controlling thrips infestations in seedling cotton and to quantify the residual levels of aldicarb and aldicarb metabolites present within the treated plants at specific points during the growing season. Tests were conducted at two locations in Georgia with different climatic/edaphic features (Piedmont and Coastal Plain) to evaluate the efficacy of precision placement in different cotton-growing environments.

Materials and Methods

Study Sites and Experimental Design. Cotton plots were established during 1999 and 2001 at the University of Georgia's Plant Sciences Farm near Athens, in the Piedmont area of Georgia, and in 2000 and 2001 at the University of Georgia's Coastal Plain Experiment Station near Tifton, in the Coastal Plain area of Georgia. Treatment plots were arranged in a randomized complete block design with four replications. One untreated check was included in each replication. For all tests, Bollgard NuCotn 33^{B} (Monsanto, St. Louis, MO) cotton seed was planted using a hill method (seeds are grouped together in hills rather than

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planted individually along the row) using a two-row Monosem pneumatic planter (Monosem, Lenexa, KS). Hills were spaced 0.3 m apart in 1-m-wide rows with three seeds per hill. Seed was planted on 12 May 1999 and 8 May 2001 for the Piedmont tests, and on 4 May 2000 and 2 May 2001 for the Coastal Plain tests.

Granular aldicarb (Temik 15G) was applied at planting using two methods. For the in-furrow application, aldicarb was applied in the furrow along the entire row with the seed using a tractor-mounted Gandy (Gandy Corp., Watonna, MN) mechanical granular applicator. After the granules had been applied, the furrow was closed with the packer-wheel device that is standard with Monesem planters. The second method, precision placement, used the same planter, but the furrow closure apparatus was disengaged so planted seed was exposed. Insecticide granules were then placed directly on top of the seed with a bazooka applicator designed to place calibrated quantities of insecticide onto the top of the seeds by a trap release system (Wiseman et al. 1980). Open furrows were then closed with a hoe. Rates of aldicarb were not the same for both methods of application. In-furrow treatments were applied at rates of 0.28, 0.56, 1.12, and 3.92 kg product per ha. Precision-placed treatments were applied at rates of 0.18, 0.71, 1.44, 2.87, and 5.74 kg product per ha. All insecticide rates were specified as kg product per ha based on 1-m-wide rows.

The two middle rows of 7.6-m-long, four-row plots were treated with varying rates of aldicarb for the 1999 Piedmont test. All four rows of 7.6-m-long, four-row plots were treated for the 2000 and 2001 Piedmont tests. The two middle rows of 15-m-long, four-row plots were treated with aldicarb for the Coastal Plain tests in 2000 and 2001.

Plots were irrigated and fertilized as needed during the growing season. No other insecticide treatments were applied to test plots.

Thrips Sampling. After planting, test plots were sampled for thrips at approximate 10-d intervals. Plants were sampled by randomly selecting 10 plants from the treated rows of each plot. Whole plants were immersed in a 120-ml specimen cup containing 60 ml of 70% ethyl alcohol. For later sampling dates when plants were larger, only the upper one-third of the plant was used. Thrips were identified, and adults and immature stages were counted using a dissecting scope (Oetting et al. 1993).

Thrips Damage, Phytotoxicity Ratings, and Yield. Coastal Plain test plots were evaluated for thrips damage 20 d after planting in 2000 and 2001 while plants were in the two-leaf stage. All of the treated plants within the plots were visually assessed for thrips damage, and each plot was assigned a mean damage rating: 1 = no damage; 2 = slight leaf curl; 3 = moderate leaf curl and stunting; 4 = heavy leaf distortion; 5 = severe damage and stunting, missing seedlings. Phytotoxicity ratings were used to assess any phytotoxic effects associated with higher rates of aldicarb. Plants from the Coastal Plain test plots were evaluated for possible phytotoxic effects from aldicarb treatments at 11 d after planting in 2000 and 12 d after planting in 2001 when plants were in the cotyledon stage. Plants from treated rows were visually assessed for insecticide phytotoxicity. Each plot was assigned a rating: 0 = no aldicarb effect; 1 = slight leaf chlorosis; 2 = minor chlorosis of leaves and slight stunting; 3 = moderate chlorosis, some browning and stunting; 4 = heavy browning of foliage and stunting to plants.

Treated rows of all tests were harvested with a two-row picker, and seed cotton was weighed in the field to determine yield.

Residual Analysis. To compare the amount of aldicarb absorbed by cotton seedlings across treatments, aldicarb residues were analyzed within plant tissues for the 1999 Piedmont and the 2000 Coastal Plain tests. Plants to be used for residue analysis were collected on the same days as the thrips sampling was conducted. Ten whole plants were randomly selected from treated rows, bagged, and frozen until analysis. Plant samples (10–25 g) were blended with ethyl acetate and sodium sulfate, filtered, and concentrated on a rotary evaporator. Extracts were cleaned up by gel permeation chromatography, followed by florasil column chromatography. Florasil column fractions containing aldicarb or metabolites were analyzed by gas liquid chromatography.

The gas liquid chromatography (GLC) analysis was conducted using a Tremetrics model 9001 instrument (Tremetrics Chromatography Group, Austin, TX) equipped with a DB-5 megabore 30-m capillary column (Supelco Catalogue 24035, Sigma-Aldrich, St. Louis, MO), and helium carrier gas at a flow rate of 1 ml/min and Flame Photometric Detector (Tremetrics Chromatography Group) operated in the S mode. The column oven was programmed as follows: initial temperature 90°C, initial hold 1 min, program rate 5°/min, to a final temperature of 275°. Residues were calculated by comparing the square root of the peak heights with similar responses of analytical standards obtained from Accustandard (Accustandard, New Haven, CT). A fortified and blank sample was included with each set of extractions. Average residue recoveries were: aldicarb, 86.2%; aldicarb sulfone, 80.8%; and aldicarb sulfoxide, 59.2%.

Statistical Analysis. Thrips infestation densities were square root transformed and subjected to an analysis of variance (ANOVA) for each sampling date. Treatment means for thrips densities, damage ratings, phytotoxicity ratings, yield, and aldicarb residual levels were separated using PROC GLM and the Tukey Studentized Range Test, with $P < 0.05$ (SAS Institute 2000). Treatment means were evaluated in comparison with the untreated check and with the standard in-furrow rate of 3.92 kg product per ha. All possible comparisons between treatments were not analyzed.

Results

For all tests, over 95% of the adult thrips sampled and counted were tobacco thrips, *F. fusca* (Hinds). Fewer than 5% of the adult thrips collected were western flower thrips, *Frankliniella occidentalis* (Pergrande).

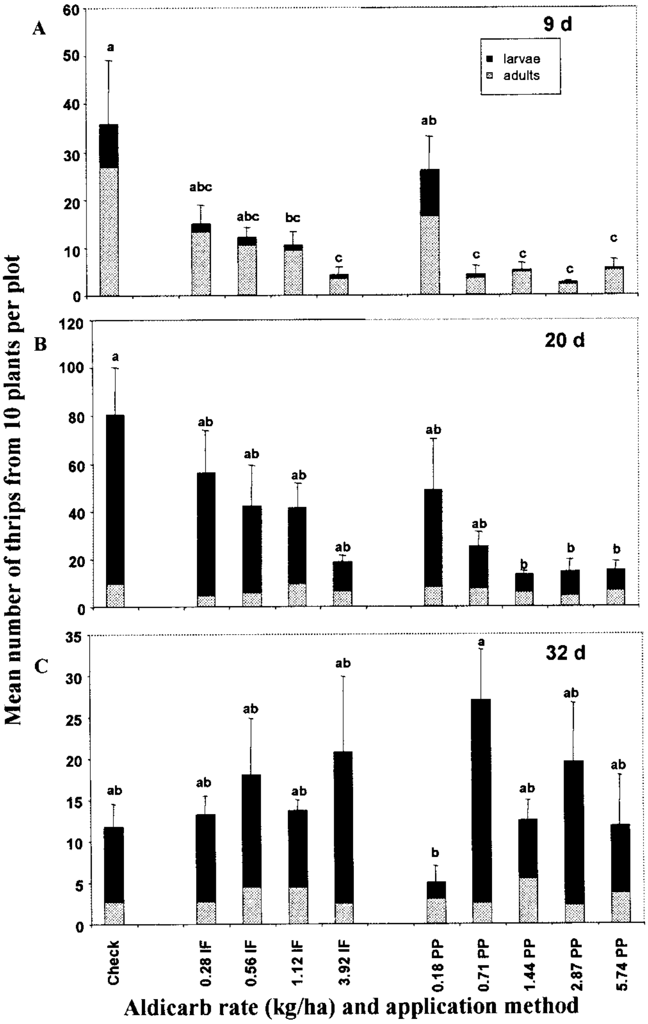

Fig. 1. Mean number of thrips (±SE) collected from 10 plants per plot, at 9 (A), 20 (B), and 32 (C) d after treatment with aldicarb, Coastal Plain region, Tifton, Georgia, 2000. Actual means; means were square root transformed before analysis. Bars with the same letter are not significantly different ($P > 0.05$, Tukey test). IF = in-furrow; PP = precision placement.

Thrips Counts. The following efficacy results are representational of the data observed for all field tests conducted from 1999 to 2001.

Coastal Plain 2000. Cotyledon stage plants were predominantly infested with adult thrips at 9 d post-treatment (Fig. 1A). Significantly fewer total thrips were observed for all treatments, except the lowest rate of precision-placed aldicarb at 0.18 kg product per ha and the in-furrow rates of aldicarb at 0.28 and 0.56 kg product per ha when compared with the untreated check ($F = 8.34$; df = 9, 27; $P < 0.0001$). All precision-placed treatments, except the lowest rate of 0.18 kg product per ha, were as effective in reducing total thrips populations as the standard in-furrow rate of 3.92 kg product per ha. Plants from plots treated with precision-placed aldicarb at rates of 1.44, 2.87, and 5.74 kg product per ha had significantly higher phytotoxicity ratings when compared with the plants from the untreated check and plants from plots treated with the standard in-furrow 3.92 kg product per ha rate ($F = 18.88$; df = 9, 27; $P = 0.0001$).

Plants were in the two-leaf stage at 20 d post-treatment and were predominantly infested with larval thrips (Fig. 1B). Significantly reduced numbers of total thrips were observed in precision-placed aldicarb treatments at 1.44, 2.87, and 5.74 kg product per ha when compared with the untreated check ($F = 2.81$; df = 9, 27; $P = 0.0182$). All precision-placed treatments were as effective in reducing total thrips populations as the standard in-furrow rate of 3.92 kg product per ha. Thrips damage ratings for plots at 20 d post-treatment showed that all of the precision-placed aldicarb treatments had significantly limited thrips damage when compared with the untreated check, except for the lowest rate of 0.18 kg product per ha ($F = 14.09$; df = 9, 27; $P = 0.0001$).

The cotton plants had four leaves at 32 d post-treatment and were predominantly infested with lar-

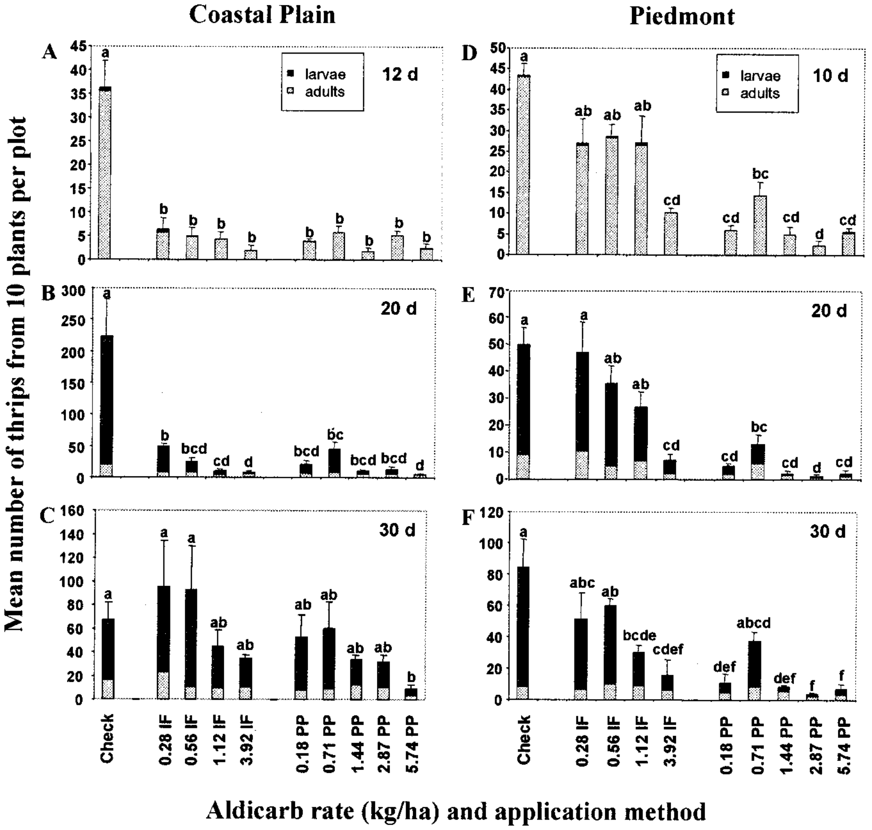

Fig. 2. Mean number of thrips (±SE) collected from 10 plants per plot, at 12 (A), 20 (B), and 30 (C) d after treatment with aldicarb, Coastal Plain region, Tifton, Georgia, 2001, and mean number of thrips (±SE) collected from 10 plants per plot, at 10 (D), 20 (E), and 30 (F) d after treatment with aldicarb, Piedmont region, Athens, Georgia, 2001. Actual means; means were square root transformed before analysis. Bars with the same letter are not significantly different ($P > 0.05$, Tukey test). IF = in-furrow; PP = precision placement.

val thrips (Fig. 1C). However, infestations of all thrips stages had dropped since the previous sampling date. All precision placement treatments were as effective in reducing total thrips as the standard in-furrow 3.92 kg product per ha rate ($F = 2.12$; df = 9, 27; $P = 0.0063$). General observations of plant growth in the test after 10 d post-treatment revealed no phytotoxic symptoms for any of the treatments.

Coastal Plain 2001. Cotyledon stage plants were predominantly infested with adult thrips at 12 d post-treatment (Fig. 2A). Significantly reduced numbers of total thrips were observed for all aldicarb treatments when compared with the untreated check ($F = 10.60$; df = 9, 27; $P < 0.0001$). All the precision-placed treatments showed as significant a reduction in total thrips as the standard in-furrow 3.92 kg product per ha rate. Precision-placed aldicarb treatments at rates of 1.44, 2.87, and 5.74 kg product per ha induced significantly greater phytotoxicity ratings when compared with plants in the untreated check plots and the standard in-furrow 3.92 kg per ha treatments ($F = 22.87$; df = 9, 27; $P = 0.0001$).

The cotton plants were in the two-leaf stage at 20 d post-treatment and were predominantly infested with larval thrips (Fig. 2B). All insecticide treatments had significantly reduced total numbers of thrips when compared with the untreated check. Efficacy was greatest in treatments of in-furrow aldicarb at a rate of 3.92 kg product per ha and precision-placed aldicarb at a rate of 5.74 kg product per ha ($F = 20.88$; df = 9, 27; $P < 0.0001$). All precision-placed treatments, except for 0.71 kg product per ha, were as effective in reducing total thrips numbers as the standard in-furrow rate of 3.92 kg product per ha. Thrips damage ratings for plots on this date showed that precision-placed aldicarb at 0.18, 1.44, 2.87, and 5.74 kg product per ha and in-furrow aldicarb at 1.12 and 3.92 kg product per ha had significantly reduced thrips plant damage when compared with the untreated check ($F = 7.20$; df = 9, 27; $P = 0.0001$).

At 30 d post-treatment, the cotton plants had four leaves and were predominantly infested with larval thrips (Fig. 2C). Only precision-placed aldicarb at a rate of 5.74 kg product per ha significantly reduced total thrips populations compared with the untreated check ($F = 3.46$; df = 9, 27; $P = 0.0059$). All precision-placed treatments were as effective in reducing total thrips populations as the standard in-furrow rate of

3.92 kg product per ha. Observations for phytotoxicity symptoms in plants showed no differences among treatments.

Piedmont 2001. At 10 d post-treatment, cotyledon stage plants in the field were predominantly infested with adult thrips (Fig. 2D). All precision-placed treatments significantly reduced total thrips populations in comparison with the untreated check ($F = 19.82$; df = 9, 27; $P < 0.0001$).

Plants were in the two-leaf stage at 20 d post-treatment and were predominantly infested with larval thrips (Fig. 2E). All precision-placed treatments significantly reduced total thrips populations in comparison with the untreated check ($F = 12.02$; df = 9, 27; $P < 0.0001$). Precision-placed aldicarb at 2.87 kg product per ha showed the greatest reduction in total thrips in comparison with the untreated check.

At 30 d post-treatment, plants had four leaves and were predominantly infested with larval thrips (Fig. 2F). All precision-placed treatments had significantly reduced numbers of total thrips when compared with the untreated check, except for 0.71 kg product per ha ($F = 12.66$; df = 9, 27; $P < 0.0001$).

Yield. For the 1999 Piedmont test, seed cotton yield varied from a high of 2,574.0 kg per ha in plots treated with the in-furrow rate of 0.56 kg product per ha to 1,858.9 kg per ha in the untreated check; however, the differences were not significant ($F = 1.00$; df = 11, 33; $P = 0.4693$).

In the 2000 Coastal Plain test, seed cotton yield varied from a high of 2,515.5 kg per ha in plots treated with precision-placed aldicarb at a rate of 0.71 kg product per ha to 1,961.7 kg per ha in the untreated check. No significant differences in yield were observed ($F = 0.74$; df = 9, 27; $P = 0.6711$).

For the 2001 Coastal Plain test, seed cotton yield in all of the precision placement-treated plots (2,782.2–2,875.2 kg per ha) was significantly higher than the yield from the untreated check (2,185.3 kg per ha), except for the lowest rate of 0.18 kg product per ha (2,551.3 kg per ha) ($F = 3.22$; df = 9, 27; $P = 0.0088$). All precision placement-treated plots had yields that were as high as those from plots treated with the standard in-furrow rate of 3.92 kg product per ha (2,717.5 kg per ha).

Significantly more seed cotton was produced in plots treated with precision-placed aldicarb at a rate of 0.18 kg product per ha (4,157.8 kg per ha) in comparison with the untreated check (1,618.5 kg per ha) ($F = 3.70$; df = 9, 27; $P = 0.0039$) for the 2001 Piedmont test. Yield from all of the precision placement-treated plots (1,899.7–4,157.8 kg per ha) was significantly as high or higher than the yield from plots treated with the standard in-furrow treatment of 3.92 kg product per ha (1,926.7 kg per ha).

Aldicarb Residual Analysis. Aldicarb is absorbed by growing cotton seedlings quickly upon germination. The growing plant metabolizes aldicarb into two byproducts: rapidly to a sulfone form and then more slowly to a sulfoxide metabolite (Coppedge et al. 1967). These metabolites are responsible for the insecticidal properties of aldicarb (Montgomery 1993). The following residual analysis data for the Coastal Plain 2000 test are also representational of the samples collected from the Piedmont 1999 test.

Coastal Plain 2000. Residual samples were taken at approximate 10-d intervals from treated plots. Residual samples taken at 9 d post-treatment showed significantly more aldicarb residue in plants treated with precision placement at a rate of 5.74 kg product per ha than the untreated check ($F = 2.62$; df = 9, 27; $P = 0.0254$) (Fig. 3A). Plants from all the precision placement treatments contained as much or more aldicarb residue than plants from the standard in-furrow treatment of 3.92 kg product per ha. Significantly more sulfone residue was found in plants treated by precision placement at rates of 2.87 and 5.74 kg product per ha when compared with the untreated check and the standard in-furrow rate of 3.92 kg product per ha rate ($F = 10.55$; df = 9, 27; $P < 0.0001$). Significantly more sulfoxide residue was found in plants treated by precision placement at a rate of 5.74 kg product per ha when compared with the untreated check and the standard in-furrow 3.92 kg product per acre rate ($F = 4.02$; df = 9, 27; $P = 0.0024$).

At 20 d post-treatment, significantly more aldicarb residue was present in plants treated by precision placement at a rate of 5.74 kg product per ha as compared with the untreated check ($F = 3.72$; df = 9, 27; $P = 0.0038$) (Fig. 3B). All plants treated with the precision-placed treatment rates had as much or more aldicarb present as those in the standard in-furrow 3.92 kg product per ha rate. Precision placement rates of 1.44, 2.87, and 5.74 kg product per ha had significantly higher amounts of sulfone residue present when compared with the untreated check ($F = 6.67$; df = 9, 27; $P < 0.0001$). When compared with the untreated check, significantly higher sulfoxide residue levels were observed for all the precision-placed treatments ($F = 9.21$; df = 9, 27; $P < 0.0001$). The precision-placed aldicarb treatments of 0.71, 1.44, and 5.74 kg product per ha had the highest sulfoxide residue levels in comparison with the check.

No significant differences in aldicarb residue levels at 32 d post-treatment were found for any treatment in comparison with the untreated check ($F = 1.00$; df = 9, 27; $P = 0.4635$) (Fig. 3C). Significantly more sulfone residue was found in plants treated by precision placement at rates of 1.44, 2.87, and 5.74 kg product per ha as compared with untreated plants ($F = 11.68$; df = 9, 27; $P < 0.0001$). Significantly more sulfoxide residue was found in plants treated by precision placement at a rate of 2.87 and 5.74 kg product per ha when compared with the untreated check ($F = 9.01$, df = 9, 27; $P < 0.0001$).

At 50 d post-treatment, plants from all treatments had comparable levels of aldicarb residues ($F = 1.05$; df = 9, 27; $P = 0.492$) (Fig. 3D). Significantly more sulfone residue was found in plants treated by precision placement at a rate of 5.74 kg product per ha in comparison with the untreated check ($F = 7.19$; df = 9, 27; $P < 0.0001$). No detectable levels of sulfoxide metabolite were found for any treatment.

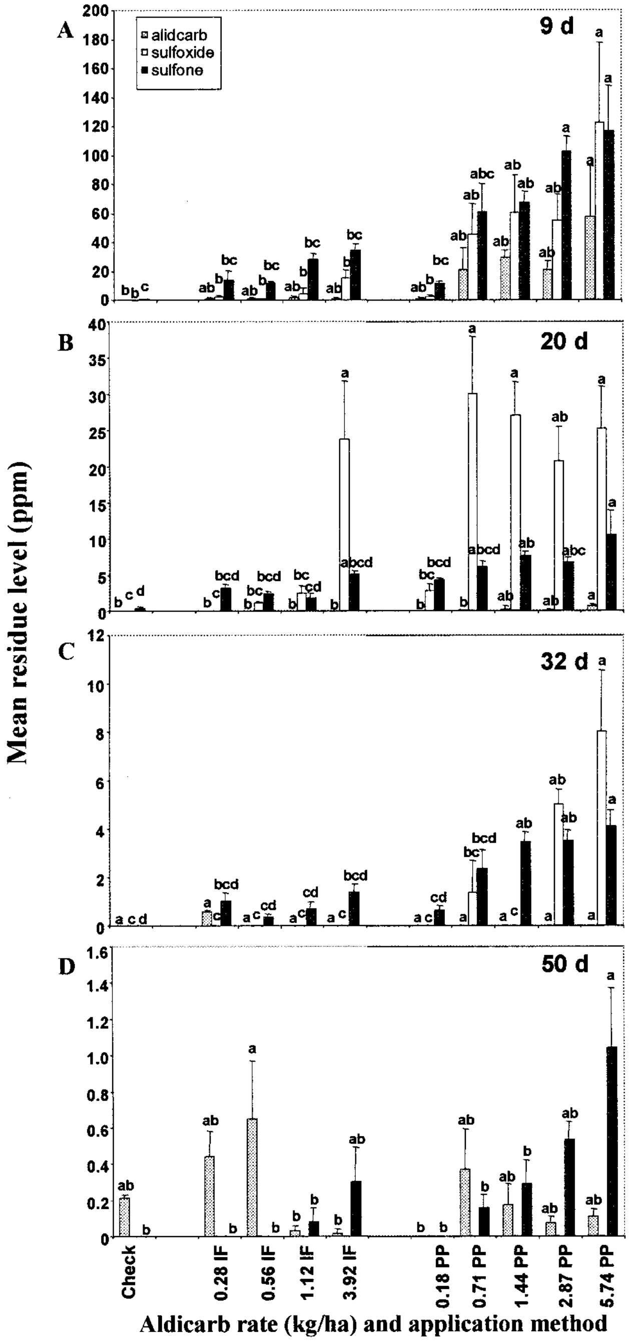

Fig. 3. Mean aldicarb and aldicarb metabolite residue levels in cotyledon stage plants at 9 (A), 20 (B), 32 (C), and 50 (D) d after treatment with aldicarb, Coastal Plain region, Tifton, Georgia, 2000. Bars with the same letter are not significantly different ($P > 0.05$, Tukey test). IF = in-furrow; PP = precision placement.

Discussion

Presently, granular applicators are not available with the capability to apply precise amounts of insecticide with seed during planting. Our results demonstrate the potential value of such a technology to reduce aldicarb use for thrips management. The various precision-placed rates of aldicarb evaluated were as effective in reducing tobacco thrips infestations as the standard in-furrow rate of 3.92 kg product per ha, but at rates that were reduced by one-half or more. In fact, precision-placed rates as low as 0.18 and 0.71 kg Temik were as effective in controlling thrips as the standard in-furrow rate of 3.92 kg Temik per ha.

Thrips damage to plants in precision placement-treated plots was comparable or less than injury to plants treated with the standard in-furrow rate of 3.92 kg product per ha. In general, plants treated with precision-placed treatments grew at a similar rate as in-furrow-treated plants, except at the higher rates of 1.44, 2.87, and 5.74 kg product per ha, in which some phytotoxicity symptoms (leaf burns) were observed during the first 20 d post-treatment.

Similar efficacy data from field tests conducted in two different climatic/edaphic regions of Georgia showed that precision-placed rates of aldicarb were effective in both regions. Also, an extreme drought occurred during the Piedmont 2001 test. Thrips counts were reduced overall because of the drought, but the precision-placed rates were still as effective in reducing total thrips populations as the standard in-furrow rate of 3.92 kg product per ha.

Precision placement plots produced yields that were as high or higher than the yields obtained from plots treated with the standard in-furrow rate of 3.92 kg product per ha. Plants that showed phytotoxic burn early in the season recovered quickly with no apparent impact on yield.

Analysis of aldicarb and aldicarb metabolite residues in cotton plants during the seedling stages showed that the insecticide quickly metabolizes into sulfone and is present in the plant at significant levels until 30 d post-treatment. Sulfone metabolizes into sulfoxide, which is present in the plant until 30 d post-treatment. At 50 d post-treatment, only trace amounts of aldicarb metabolites remain in the plant. Aldicarb metabolite levels were significantly higher in plants treated by precision placement than those receiving conventional in-furrow treatment at levels that corresponded with insect control.

Residual levels for the different treatments were found to be similar in both of the climatic/edaphic test regions. This indicates that climatic effects and soil type do not appear to affect aldicarb uptake by the growing plant.

Residual analysis verified that precision placement delivers more aldicarb to growing plants than the conventional in-furrow treatments. Thus, more aldicarb reaches the growing plant. The higher levels of aldicarb and aldicarb metabolites found in cotton seedlings during the first 30 d post-treatment appear to be the critical component for managing thrips infestations. Maximum residual levels during this 30-d period correspond with the peak thrips infestations found on cotton seedlings during the first 30 d post-treatment. When cotton seedlings are small and most vulnerable to injury, thrips populations are at their highest and aldicarb residues are also at their peak levels. As the plant grows, thrips levels and aldicarb residues diminish.

The efficacy tests in these studies show that the development of technology for precision placement of aldicarb with cotton seed during planting could be a valuable innovation for the management of thrips in cotton. Test results indicated that field rates of precision-placed aldicarb may be reduced by one-half or more and still achieve similar thrips control as conventional in-furrow treatments. Cotton growers could reduce the rate of application aldicarb from 3.92 to 1.44 kg product per ha or less and still achieve effective thrips control.

Each year, over 1.3 million ha of cotton is planted in the southeastern United States (Williams 2002). If growers were able to reduce the amount of aldicarb put into the field from 3.92 to 1.44 kg per ha, this could mean a savings of over $23,664,000 ($18 per ha) in the Southeast annually in insecticide costs as well as a reduction in the amount of aldicarb being applied to the field from 5,096,000 to 1,872,000 kg.

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References Cited

Coppedge, J. R., D. A. Lindquist, D. L. Bull, and H. W. Dorough. 1967. Fate of 2-methyl-2-([methylthio]propionaldehyde) *O*-(Methylcarbamoyl) oxime (Temik®) in cotton plants and soil. J. Agric. Food Chem. 15(5): 902–910.

Davidson, R. H., L. M. Peairs, and W. F. Lyon. 1979. Insect pests of farm, garden, and orchard, 7th ed. Wiley, New York.

Hayes, W. J., Jr. 1982. Pesticides studied in man. Waverly Press, Baltimore, MD.

Howard, P. H. 1991. Handbook of environmental fate and exposure data for organic chemicals, vol. III. Lewis Publishers, Chelsea, MI.

Montgomery, J. H. 1993. Agrochemicals desk reference: environmental data. Lewis Publishers, Chelsea, MI.

Oetting, R. D., R. J. Beshear, T. Liu, S. K. Braman, and J. R. Baker. 1993. Biology and identification of thrips on greenhouse ornamentals: Research Bulletin 414. Georgia Agricultural Experiment Stations, College of Agricultural and Environmental Sciences, University of Georgia, Athens.

SAS Institute. 2000. SAS user's guide: statistics, version 8.2. SAS Institute, Cary, NC.

Thelin, G. P. 1998. USGS–pesticide annual use map. http://ca.water.usgs.gov/pnsp/use92/aldcrb.html.

Williams, M. R. 2001. Cotton insect loss estimates–2000. *In* C. P. Dugger and D. A. Richter (eds.), Proceedings, Beltwide Cotton Conferences, 9–13 January 2001, Anaheim, CA. National Cotton Council of America, Memphis, TN.

Williams, M. R. 2002. Cotton insect losses–2001. *In* J. McRae and D. A. Richter (eds.), Proceedings, Beltwide Cotton Conferences, 8–10 Jan 2002, Atlanta, GA. National Cotton Council of America, Memphis, TN.

Wiseman, B. R., F. M. Davis, and J. E. Campbell. 1980. Mechanical infestation device used in fall armyworm *Spodoptera frugiperda* plant resistance programs. Fla. Entomol. 63: 424–432.

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